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CTT

Hogeschool van Utrecht

Systeem en Regeltechniek
FMT / Mechatronica

Deel 5: Toepassing: PID regelaarontwerp
Oefening: Toepassing: Tunen PID regelaar mechatronisch systeem
(update dd. 21-05-2004)

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Cursus Systeem en Regeltechniek
Overzicht

Deel 1	Blok 1.	Inleiding
Wo. 14-04	Blok 2.	Basisprincipes modelvorming massa-veersystemen
	Blok 3.	De regelaar als veer-demper combinatie
Deel 2	Blok 4.	Frequentie-domein beschrijving
Wo. 21-04	Blok 5.	Basisconcepten in de regeltheorie
Deel 3	Blok 6.	Verdere inleiding in de regeltheorie
Wo. 28-04	Blok 7.	De PD regelaar als veer-demper combinatie
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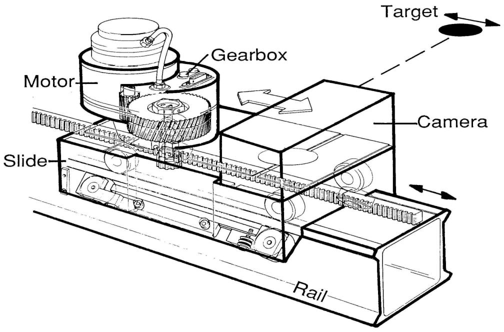
Wo. 12-05	Blok 9.	De PID regelaar in het frequentie domein
Deel 5	Blok 10.	Bandbreedte en verstoringsonderdrukking
Wo. 19-05	Blok 11.	Toepassing: Tunen PID regelaar mechatronisch systeem
Deel 6 *Wo. 26-05*	**Extra regeltechniek**	

Tuning the PID controller: what does that mean in practice?

?

Mechatronic system



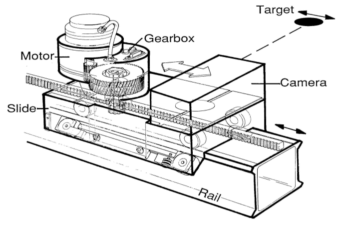
Moving target:	**3 Hz, 3mm**
Allowed tracking error:	**40µm**

Data Mechanics

Motor inertia:	**2.5×10^{-5} [Kgm^2]**
Motor gear wheel inertia:	**2.5×10^{-5} [Kgm^2]**
Gear+pinion wheel inertia:	**5.0×10^{-5} [Kgm^2]**
Mass slide:	**5.0 Kg**
Mass camera:	**3.0 Kg**
Transmission gearbox:	**0.2 [-]**
Diameter pinion wheel:	**30 [mm]**

Objective Exercise

- Dimension a stable control loop in which the error is reduced to 40 µm
- The phase margin at the crossover is about 50 degrees



Moving target: **3 Hz, 3mm**

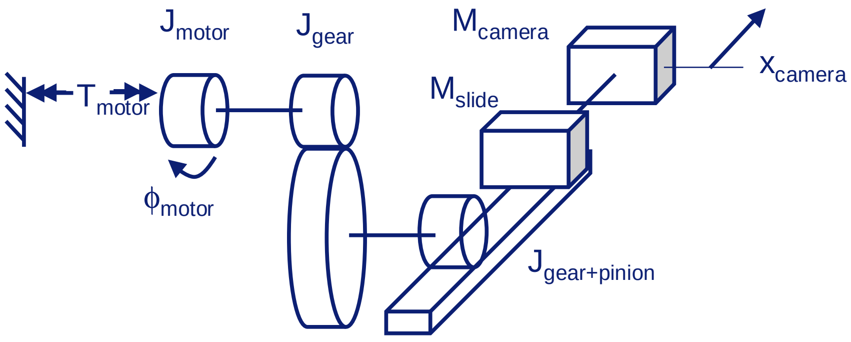
Allowed tracking error: 40µm

Exercise - Part 1

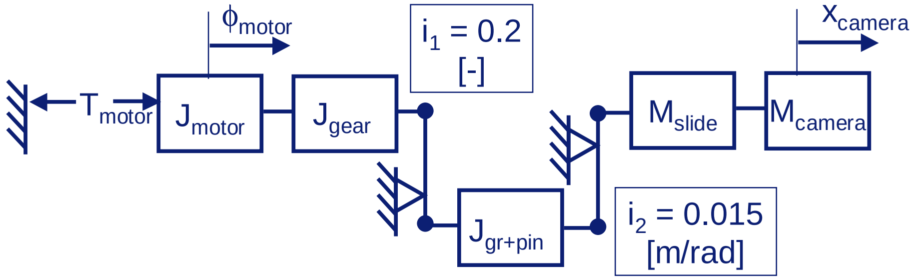
Solve the sketched control problem for a system without flexibilities

- Assignment 1:
  Sketch a simple model without flexibilities
  - All elements included
  - Reduced model with single mass
- Assignment 2:
  Implement the model in 20-sim
- Assignment 3:
  Design a PD controller and check performance

Assignment 1:
Model without flexibilities

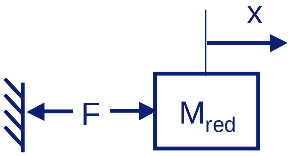


Assignment 1:
Model without flexibilities

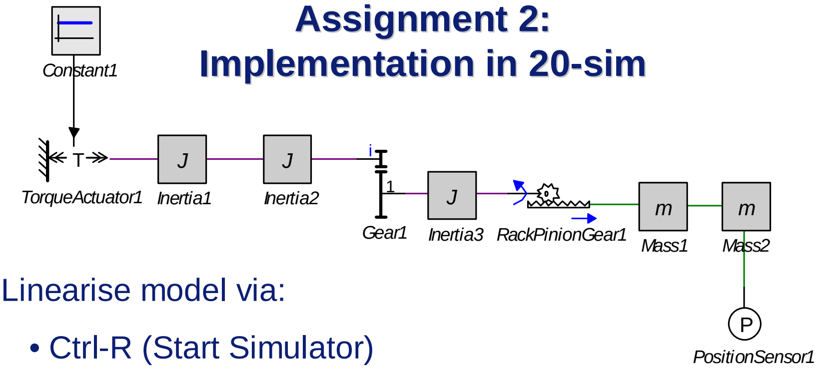


Reduced model (to camera):

$$M_{red} = M_{camera} + M_{slide} + J_{gr+pin}/i_2^2 + (J_{gear}+J_{motor})/(i_1^2 i_2^2)$$



Assignment 2:
Implementation in 20-sim



- Linearise model via:
  - Ctrl-R (Start Simulator)
  - Tools – Model Linearisation; choose option ‘Numeric’
- Does the ‘Mass’ of the obtained model correspond to the reduced mass? No! Why not? And why is the minus sign?!
- Use obtained linear system (transfer function properties) as ‘Plant’ in new submodel ‘Controlled Linear System’

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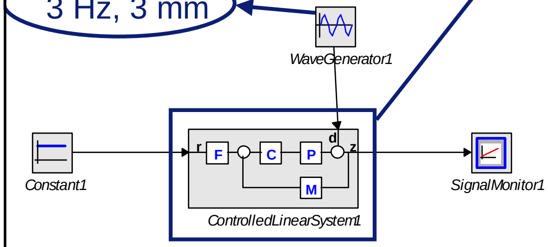
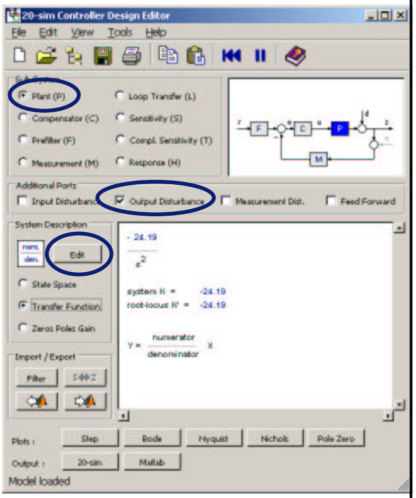
Assignment 2: Implementation in 20-sim

Build controlled linear system as follows:

3 Hz, 3 mm





● Plant (P)

☑ Output Disturbance

● Transfer Function

$$\frac{-24.19}{s^2}$$

system K = -24.19
root-locus K' = -24.19

$$Y = \frac{\text{numerator}}{\text{denominator}}\ X$$

Model loaded

Now the controller design can be performed

Application: Tuning PID controller mechatronic system

Assignment 3: Design a PD controller and check performance

Follow these steps:

1. Determine the needed reduction at 3 Hz
2. Determine the needed bandwidth f_b (0 dB crossing of open loop), assuming Kp controller
3. Tune a Lead Filter (also called lead-lag):
    1. Adjust the width of the lead-lag filter (f_1; f_2) for the required phase margin; position the lead-lag around the required bandwidth by choosing: $f_1 = f_b/n$; $f_2 = f_b*n$
    2. Adjust the gain to place the 0 dB crossing of the open loop at the required bandwidth
4. Check stability in Nyquist; check the reduction at 3 Hz in sensitivity plot
5. Repeat tuning Lead Filter if necessary
6. Check the reduction via a time plot with 3 Hz sine

Assignment 3:
Design a PD controller and check performance

Step 1: Determine the needed reduction at 3 Hz

S (3Hz) = e (3Hz) / d (3Hz) = 40 μm / 3 mm = 0.013

So a reduction of the error with a factor 75 is needed @ 3 Hz

This corresponds to a sensitivity value @ 3 Hz of -37,5 dB

With S = 1 / (1 + L), with L the open loop response C(s)H(s), this means roughly that L should be larger than 37,5 dB @ 3 Hz

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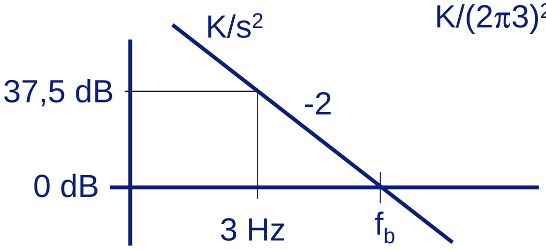
Assignment 3:
Design a PD controller and check performance

Step 2: Determine the needed bandwidth f_b

So we have: C(s)H(s) > 37,5 dB @ 3 Hz

Assuming a Kp controller, the open loop looks like: K/s^2



$K/(2\pi 3)^2 = 75$; $K/(2\pi f_b)^2 = 1$

$(f_b/3)^2 = 75$

$\mathbf{f_b = 26\ Hz}$

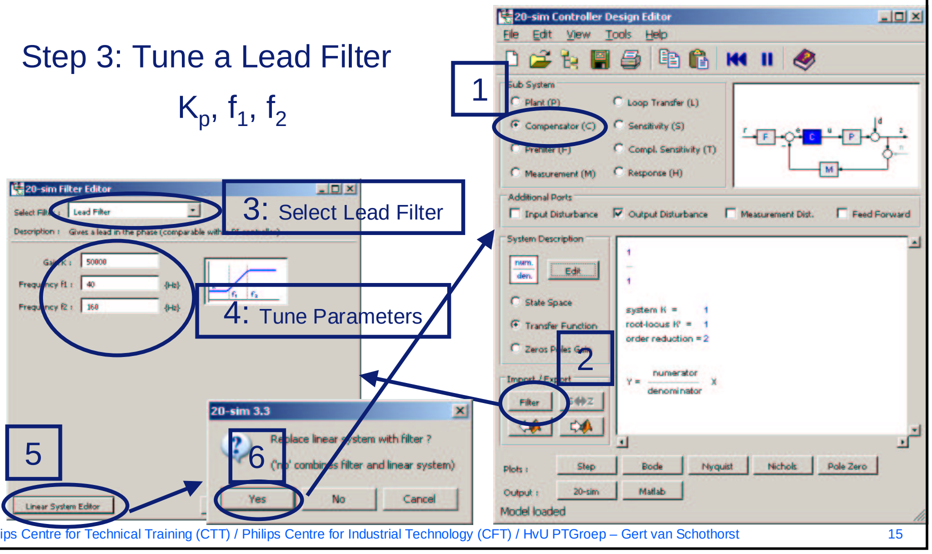
Note the minus sign!

$K_p = K / -24.19$
$= -1100$

Assignment 3:
Design a PD controller and check performance

Step 3: Tune a Lead Filter

K_p, f_1, f_2



1

● Compensator (C)

☐ Input Disturbance ☑ Output Disturbance ☐ Measurement Dist. ☐ Feed Forward

● Transfer Function

$\frac{1}{1}$

system K = 1
root-locus K' = 1
order reduction = 2

$Y = \frac{\text{numerator}}{\text{denominator}} X$

2

3: Select Lead Filter

Select Filter : Lead Filter
Description : Gives a lead in the phase (comparable with a PD controller)

Gain K : 50000
Frequency f1 : 40 {Hz}
Frequency f2 : 160 {Hz}

4: Tune Parameters

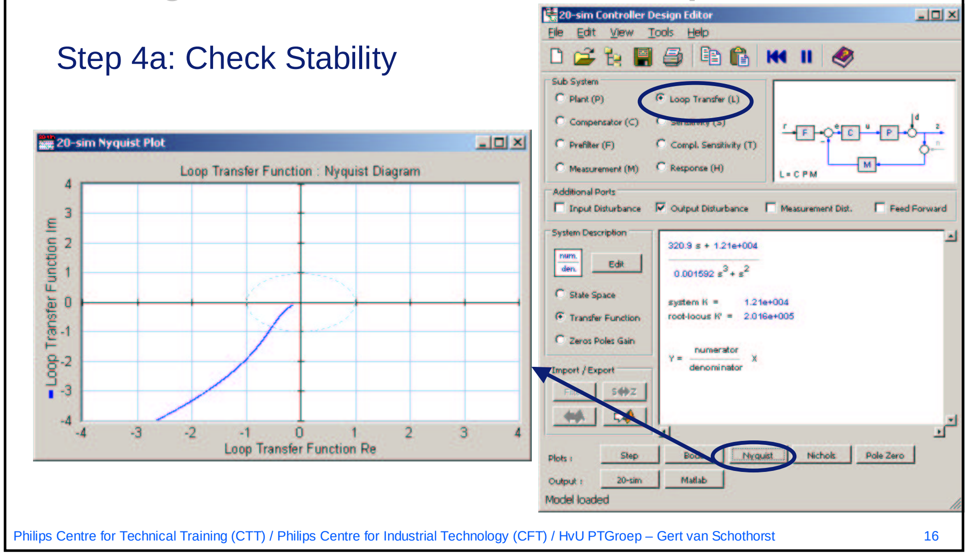
5

6

Replace linear system with filter ?
('no' combines filter and linear system)

Assignment 3:
Design a PD controller and check performance

Step 4a: Check Stability



● Loop Transfer (L)

☐ Input Disturbance ☑ Output Disturbance ☐ Measurement Dist. ☐ Feed Forward

● Transfer Function

$\frac{320.9\ s + 1.21e{+}004}{0.001592\ s^3 + s^2}$

system K = 1.21e+004
root-locus K' = 2.016e+005

$Y = \frac{\text{numerator}}{\text{denominator}} X$

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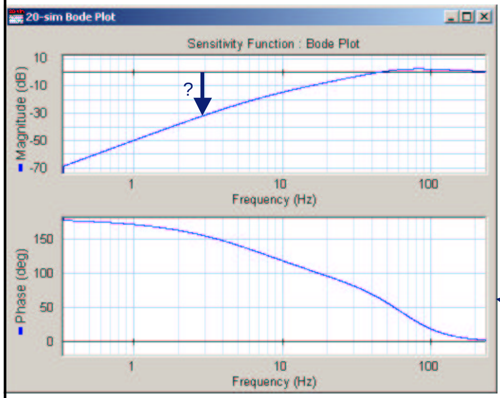
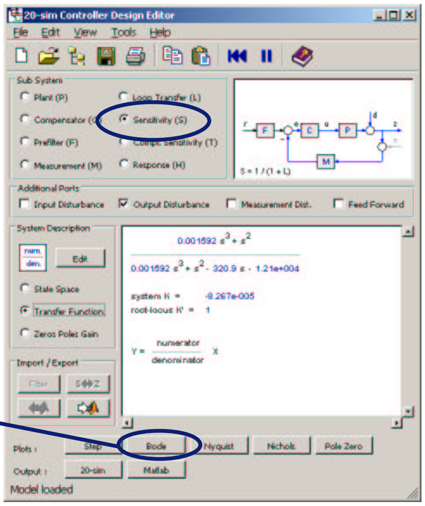
Assignment 3:
Design a PD controller and check performance

Step 4b: Check Sensitivity





● Sensitivity (S)

● Transfer Function

☐ Input Disturbance ☑ Output Disturbance ☐ Measurement Dist. ☐ Feed Forward

$$\frac{0.001592\, s^3 + s^2}{0.001592\, s^3 + s^2 - 320.9\, s - 1.21e{+}004}$$

system K = -8.267e-005

root-locus K' = 1

$$Y = \frac{\text{numerator}}{\text{denominator}}\ X$$

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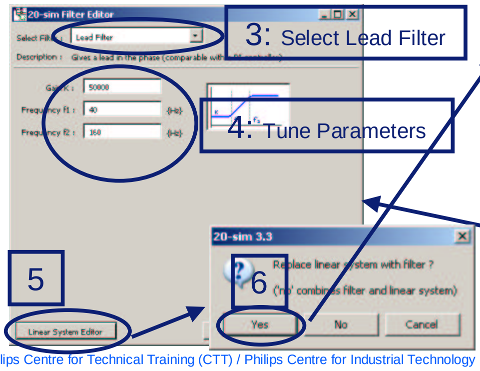
Assignment 3:
Design a PD controller and check performance

Step 5: Retune Lead Filter

if necessary



Select Filter : Lead Filter

Description : Gives a lead in the phase (comparable with a PI controller)

Gain K : 50000

Frequency f1 : 40 {Hz}

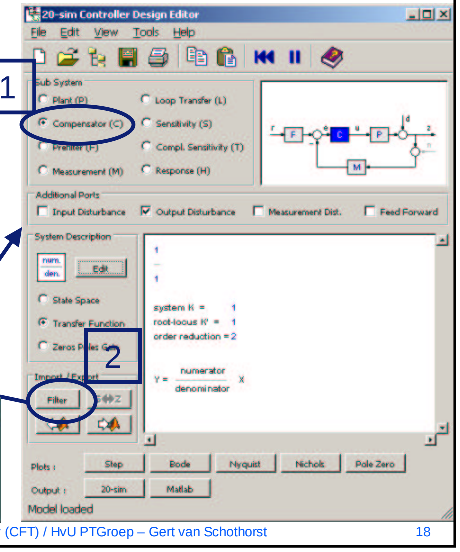
Frequency f2 : 160 {Hz}

3: Select Lead Filter

4: Tune Parameters

Replace linear system with filter ?

('no' combines filter and linear system)



● Compensator (C)

● Transfer Function

☐ Input Disturbance ☑ Output Disturbance ☐ Measurement Dist. ☐ Feed Forward

$$\frac{1}{1}$$

system K = 1

root-locus K' = 1

order reduction = 2

$$Y = \frac{\text{numerator}}{\text{denominator}}\ X$$

Model loaded

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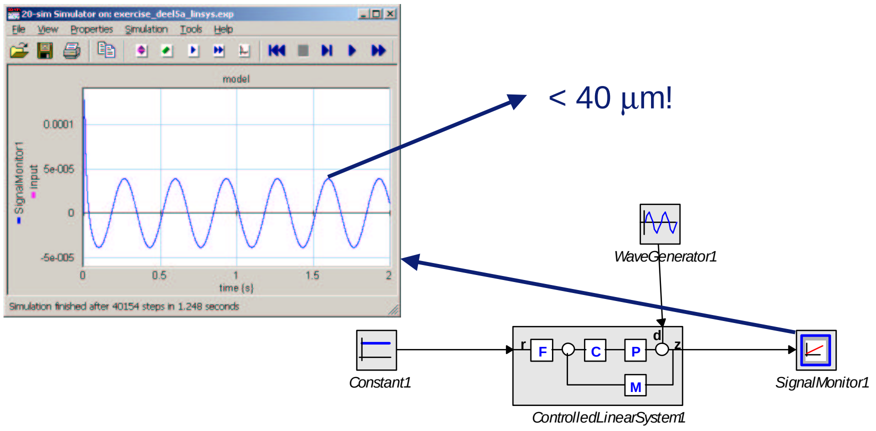
Assignment 3:
Design a PD controller and check performance

Step 6: Check time response on 3 Hz sine of 3 mm



Simulation finished after 40154 steps in 1.248 seconds

< 40 μm!

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Application: Tuning PID controller mechatronic system

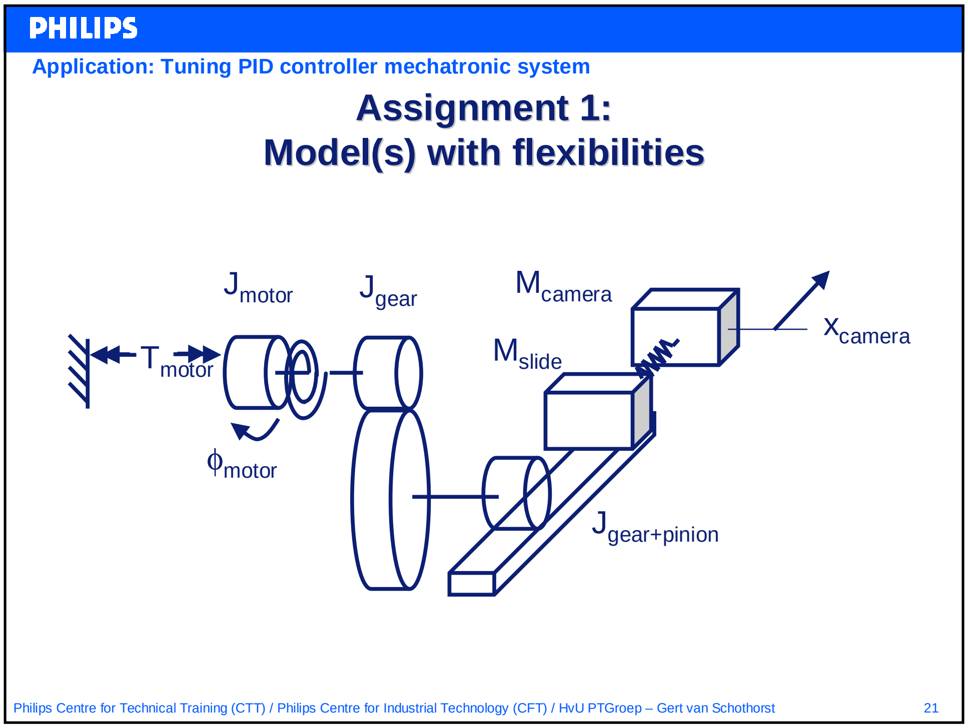
Exercise - Part 2

Analyse the dynamics of a flexible system

- Assignment 1:

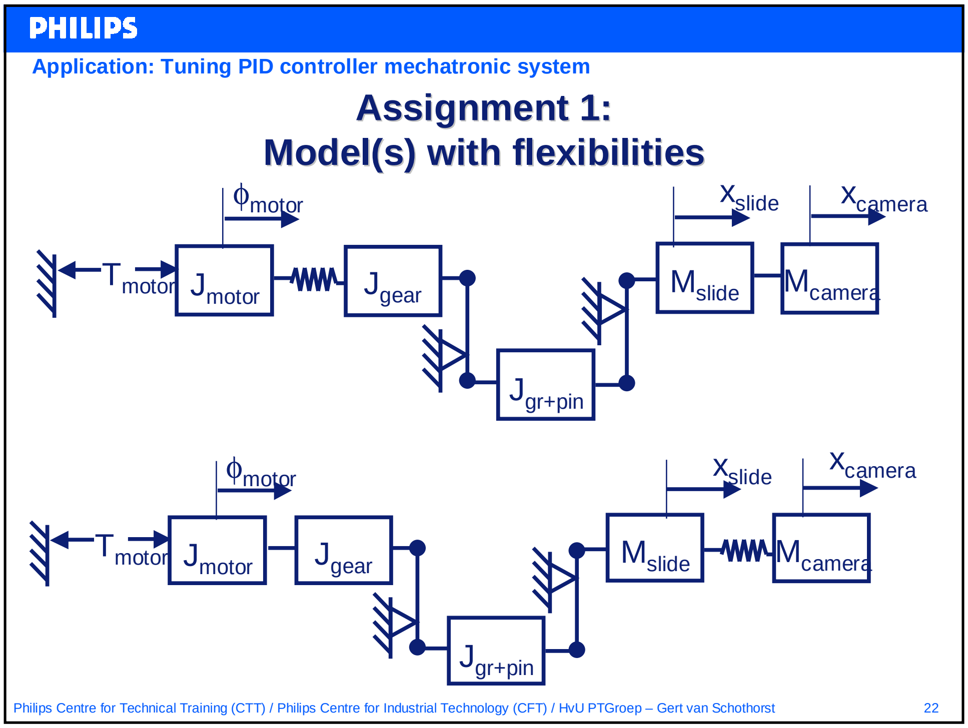
  Sketch and implement 2 models with flexibilities:
  - Motor shaft k_t = 20 [Nm/rad]; d_t = 0.001 [Nms/rad]
  - Camera suspension k = 2.4 10^6 [N/m]; d = 120 [Ns/m]
- Assignment 2:

  Compare the dynamic behavior of both systems using:
  - a rotational measurement on the motor (ϕ_{motor})
  - a linear measurement on the slide (x_{slide})



Application: Tuning PID controller mechatronic system

Assignment 1: Model(s) with flexibilities



Application: Tuning PID controller mechatronic system

Assignment 1: Model(s) with flexibilities

Assignment 2:

- Check Bode plots:
  - Minus 2 slope with resonance
  - Minus 2 slope with anti-resonance/resonance
- Compare and investigate differences:
  - Physical interpretation of anti-resonance
  - Effect on stability of control loop…

Exercise - Part 3

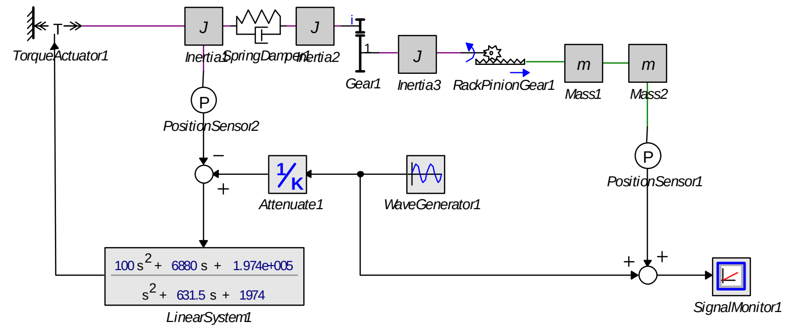
Solve the control problem again
– now for the flexible system

- Step 1: Choose the system to be controlled:
  - Choose type of flexibility:
    - Motor shaft k_t = 20 [Nm/rad]; d_t = 0.001 [Nms/rad]
    - Camera suspension k = 2.4 10^6 [N/m]; d = 120 [Ns/m]
  - Choose location of feedback sensor:
    - an encoder measurement on the motor (ϕ_{motor})
    - a linear measurement on the slide (x_{slide})
- Step 2: Design a PID controller
  - Follow same procedure as before
  - Add filters if necessary

Application: Tuning PID controller mechatronic system

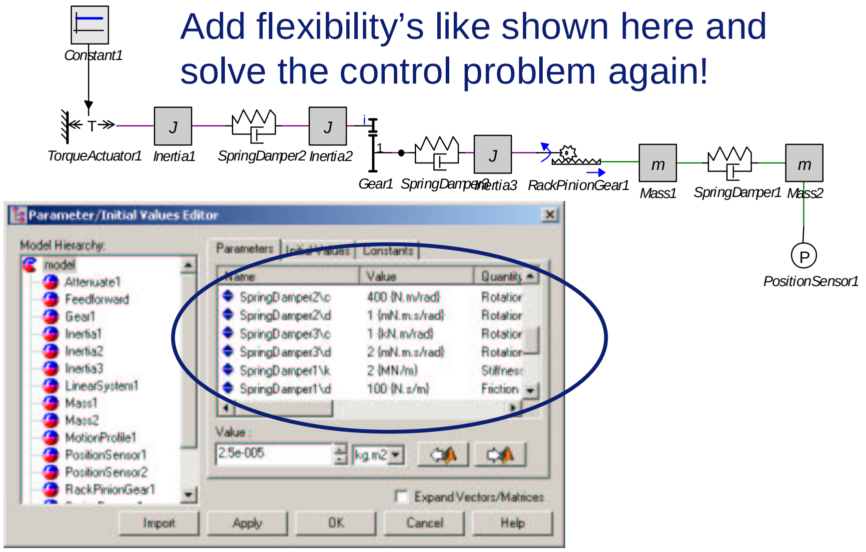
Example of implementation

Motor feedback / motor flexibility



Exercise - Part 4

Add flexibility's like shown here and solve the control problem again!



Name	Value	Quantity
SpringDamper2\c	400 {N.m/rad}	Rotation
SpringDamper2\d	1 {mN.m.s/rad}	Rotation
SpringDamper3\c	1 {kN.m/rad}	Rotation
SpringDamper3\d	2 {mN.m.s/rad}	Rotation
SpringDamper1\k	2 {MN/m}	Stiffness
SpringDamper1\d	100 {N.s/m}	Friction

Summary

- Modelling a mechatronic system in 20-sim
  - – Sketch (simplified) model
  - – Implement in 20-sim
- Loop shaping / design for performance:
  - – S small where disturbances occur
  - – High bandwidth - small S for low frequency
- Effect of mechatronic system design:
  - – Location of flexibilities
  - – Location of feedback sensors

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